Properties of a Gaussian Beam

1 Introduction

We will look at the intensity distribution of a laser beam. The output of a laser is different than that of most other light sources. The laser resonator determines the spatial characteristics of the laser beam. Most Helium Neon (HeNe) lasers have spherical-mirror Fabry-Perot resonators that have Hermite-Gaussian spatial modes. Usually only the lowest order transverse resonator (TEM_{00}) mode oscillates, resulting in a Gaussian output beam.

2 Background - *see Pedrotti*[3], *Chap. 27*

The irradiance (proportional to the square of the electric field) of a Gaussian beam is symmetric about the beam axis and varies with radial distance r from the axis as

$$I(r) = I_0 \exp(-2r^2/w_0^2) \tag{1}$$

Here w_0 is the radial extent of the beam where the irradiance has dropped to $1/e^2$ of its value on the beam axis, I_0.

A Gaussian beam has a waist, where w_0 is smallest. It either diverges from or converges to this beam waist. This divergence or convergence is measured by the angle θ which is subtended by the points on either side of the beam axis where the irradiance has dropped to $1/e^2$ of its value on the beam axis, this is the place where the electric field has dropped by $1/e$.

Under the laws of geometrical optics a bundle of rays (a beam) converging at an angle of θ should collapse to a point. Because of diffraction, this does not occur. However, at the intersection of the asymptotes that define θ, the beam diameter reaches a minimum value $d_0 = 2w_0$, the beam waist diameter.

The variation of the beam waist w as a function of propagation distance z is:

$$w(z) = w_0\sqrt{1 + \left(\frac{z}{z_0}\right)^2} \tag{2}$$

with the Rayleigh length z_0 given by:

$$z_0 = \frac{\pi w_0^2}{\lambda} \tag{3}$$

A TEM_{00} mode w_0 depends on the beam divergence angle as $w_0 = 2\lambda/\pi\theta$, where λ is the wavelength of the radiation.

the product $w_0\theta$ is constant for a Gaussian beam of a particular wavelength. A beam with a very small beam waist w_0 requires the divergence θ must be large, while for a highly collimated beam with small θ the beam waist w_0 must be large.

The most important characteristic of the beam is the phase. The phase is flat (infinite curvature) at the waist w_0, then grows to a maximum at z_0 and returns to flat at infinity. The curvature of the wave front is given by the Radius of Curvature R.

$$R(z) = z\sqrt{1 + \left(\frac{z_0}{z}\right)^2} \tag{4}$$

3 Experiment

Please be very careful when using a laser. Parallel light gets focused and that can happen with a laser beam in your retina.

In the following experiments, you will find the divergence of your laser θ, the beam waist of the laser w_0. Use the appropriate limit ($z >> z_0$) of equation 2 to define the divergence angle θ in terms of the other parameters (see figure 1).

Use the diverging lens to have a large laser beam. Take the photodetector and place the small aperture on it. You will measure the Gaussian profile of the laser using a scanning detector and the computer interface. The data will be in the form of a tex file with two columns of numbers. One for time the other for voltage that will be proportional to the irradiance. You will acquire data with the computer and then fit the data to a Gaussian. Make sure you understand the software you use for the fit.

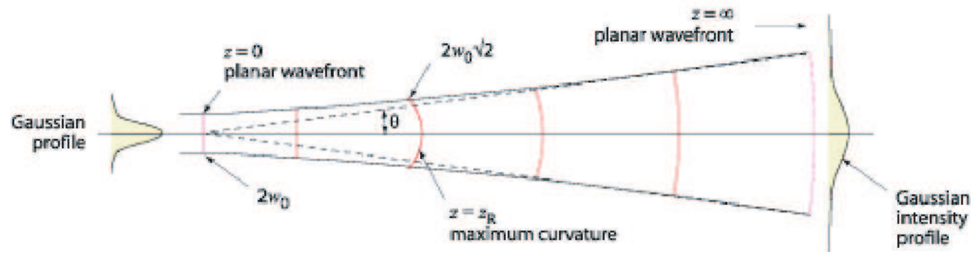

Figure 1: Gaussian Beam Propagation

The calibration of the scanner displacement vs time (as recorded by the computer) is obtained in the following way. The motor driving the scanner screw rotates at 600 rev/min and the screw pitch is 10 turn/cm A check of the calculated scanner speed should be done by actually measuring the time taken to travel a known distance.

4 Some web links

http://www.mellesgriot.com/products/optics/gb_2_1.htm

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